

SPECIFICATION OF AEROSOLS

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Presented at

ARM Science Team Meeting

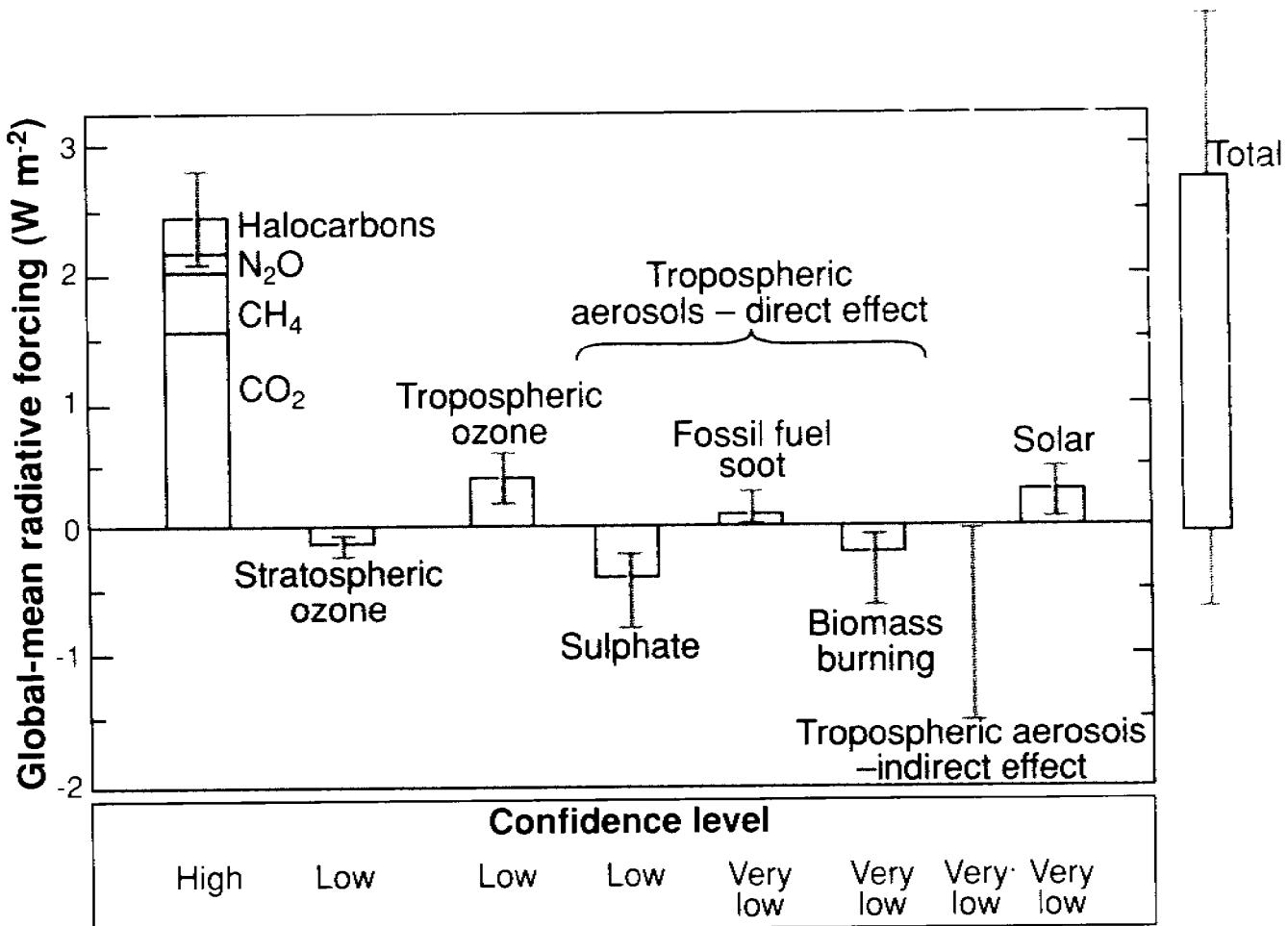
San Antonio, Texas

March 5, 1996

WHY DO WE CARE ABOUT AEROSOLS?

1. Influence of aerosols on instantaneous shortwave radiative flux. (ARM Objective 1)
 - Magnitude of *tens* of watts per square meter is important in closure studies demonstrating quantitative understanding of shortwave radiative transfer in the atmosphere.
 - Aerosols have traditionally been the “fudge factor” or “whipping boy” of atmospheric radiation science.
 - Atmospheric "corrections" for determining surface or ocean properties from satellite.
2. Influence of aerosols on cloud microphysical properties and in turn radiative properties. (ARM Objective 2)
3. Secular change in aerosols due to human activity may give rise to forcing of climate change.
4. These influences need to be represented in climate models, with known uncertainties.
(Key ARM Deliverable)

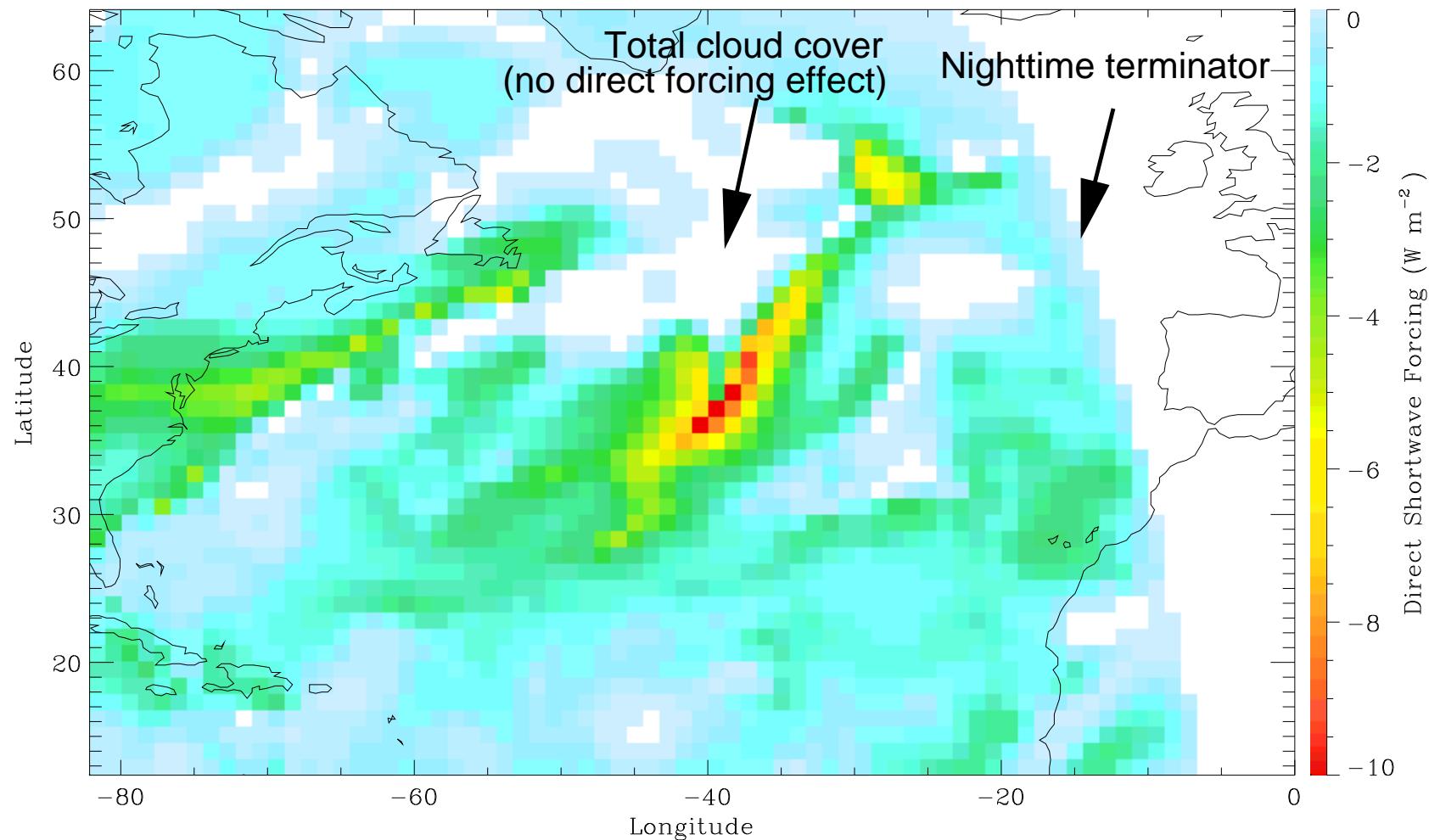
UNCERTAINTY IN AEROSOL FORCING DOMINATES UNCERTAINTY IN CLIMATE FORCING OVER THE INDUSTRIAL PERIOD



Forcing the issue. Estimates of the globally and annually averaged anthropogenic radiative forcing of climate due to (i) changes in concentrations of greenhouse gases and aerosols from preindustrial times to the present and (ii) natural changes in solar output from 1850 to the present (5). The bars denote a mid-range estimate for each forcing (an upward bar denotes a positive forcing or warming influence; a downward bar, a cooling influence); the I-beams show an estimate of the uncertainty range. Bar at right shows the total forcing as the algebraic sum of the individual component forcings and the uncertainty range for the total forcing as the sums of the upper and lower ends of the individual uncertainty ranges. The lower panel indicates the IPCC's subjective confidence that the actual forcing lies within the indicated uncertainty range.

Direct Shortwave Forcing of Sulfate Aerosol over the North Atlantic Ocean

(October 15, 1986, 1800 UT)



SENSITIVITY OF DIRECT-NORMAL SOLAR IRRADIANCE (DNSI) TO ATMOSPHERIC VARIABLES

Variable	Ångström exponent	Ozone Dobson Units	Precipitable Water cm	AOD 550	Calculated DNSI [†] W m ⁻²	DNSI W m ⁻²
Base Case *	0.6	324	1.087	0.095	805.9	
Ångström exponent	0.5	324	1.087	0.095	802.9	-3.0
Ozone	0.6	389	1.087	0.095	802.4	-3.5
PW	0.6	324	1.196	0.095	801.8	-4.1
AOD	0.6	324	1.087	0.085	819.4	13.5

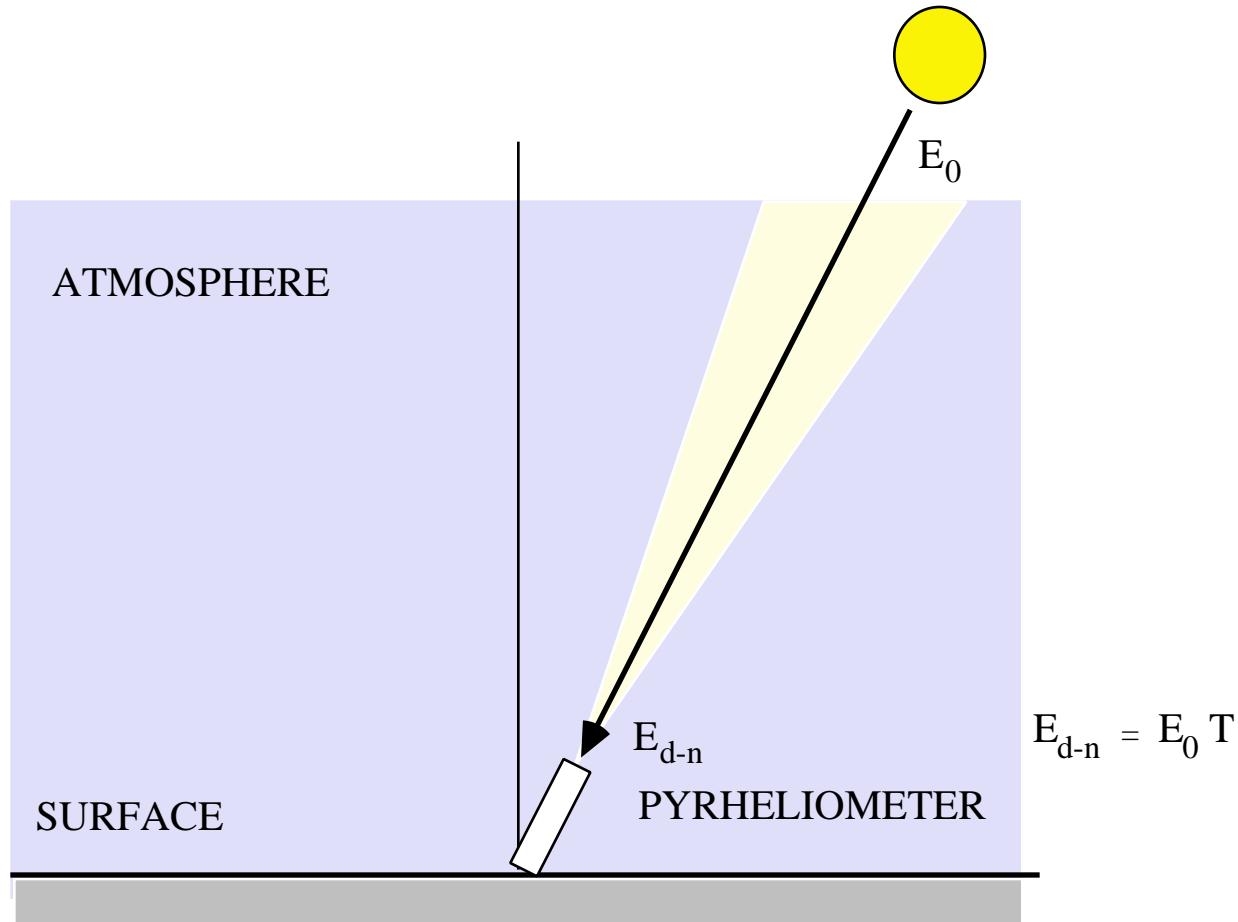
* Corresponds to CART SGP site for April 18, 1996 at 1427 UT (0827 local standard time). Solar zenith angle 59.7°. Precipitable Water (PW) from radiosonde. Aerosol Optical Depth (AOD) from Cimel Sun Photometer.

† MODTRAN-3. Assumed Solar Constant 1373 W m⁻².

DNSI is most sensitive to AOD. Change in AOD of 0.01 yields change in DNSI of 13.5 W m⁻² or 1.6%.

- Halthore *et al.*, to be submitted, 1997

WHAT IS DIRECT-NORMAL SOLAR IRRADIANCE?



$$E_{d-n} = E_0 T$$

E_{d-n} = measured direct normal solar irradiance

E_0 = direct normal solar irradiance

T = atmospheric transmittance

WHAT DO WE NEED TO KNOW ABOUT AEROSOLS?

Local *Microphysical* Properties

Surface

Function of Altitude

Local *Optical* Properties

At the Surface

Function of Altitude

Column *Radiative* Properties

“Vertical integral” of local optical properties

LOCAL MICROPHYSICAL PROPERTIES

Size distribution

Relative humidity dependence

Index of refraction

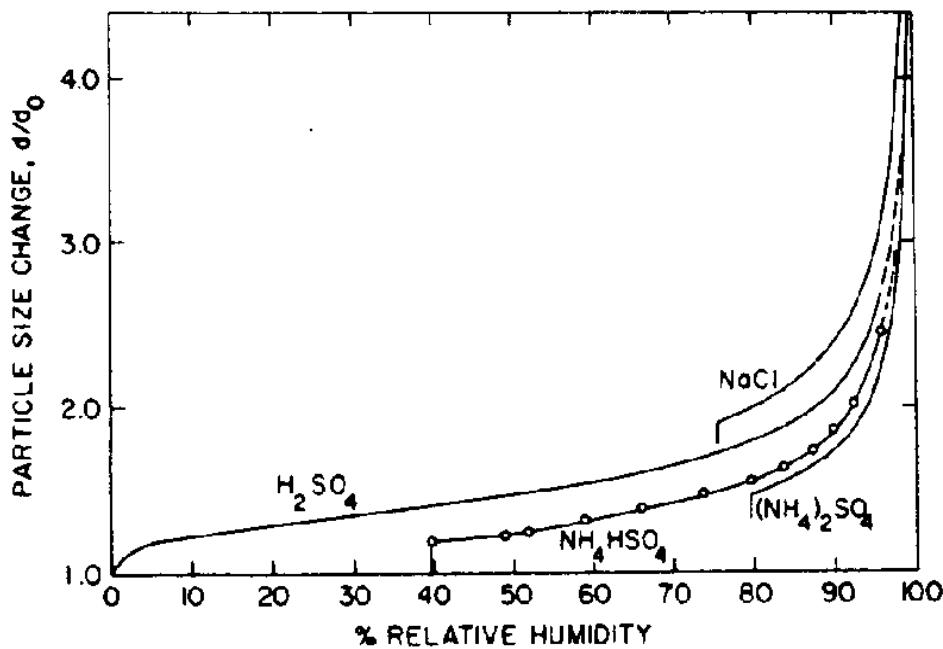
Relative humidity dependence

Chemical composition

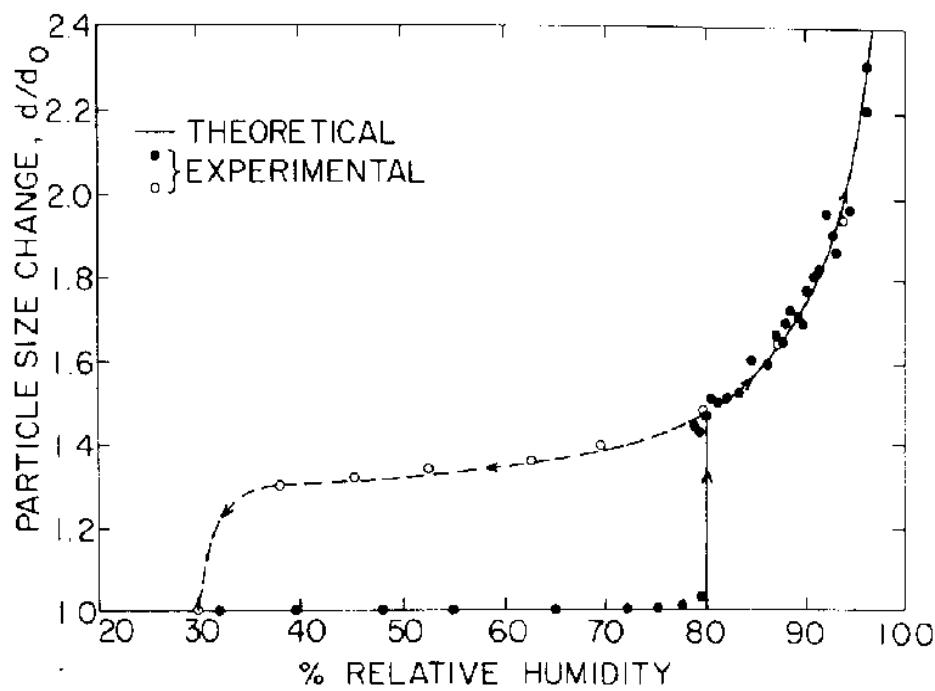
Determines index of refraction and RH effects.

Application of this information is problematic.

RELATIVE HUMIDITY INFLUENCE ON PARTICLE SIZE

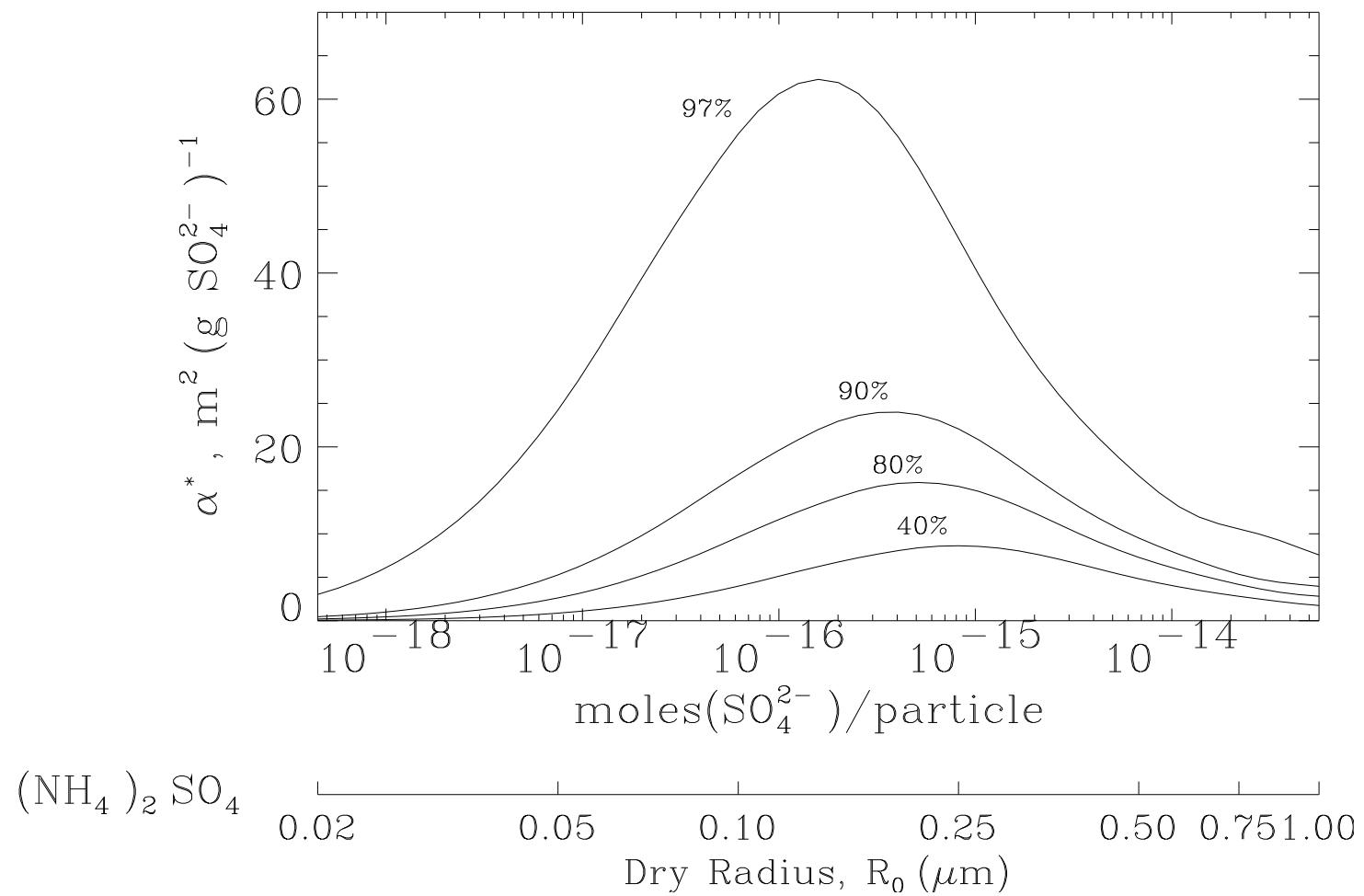


$(NH_4)_2SO_4$



I. N. Tang
Brookhaven National Laboratory

LIGHT SCATTERING CROSS SECTION OF $(\text{NH}_4)_2\text{SO}_4$:
DEPENDENCE ON PARTICLE SIZE AND RH



LOCAL OPTICAL PROPERTIES

Extensive Properties

Scattering coefficient s_p , unit: m^{-1}

Backscatter coefficient b_{sp} , unit: m^{-1}

Absorption coefficient a_p , unit: m^{-1}

Extinction coefficient $e_p = s_p + a_p$

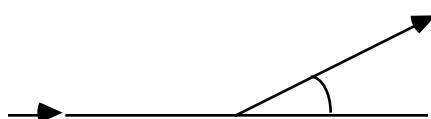
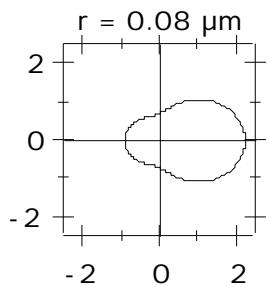
All wavelength dependent

Strong dependence of s_p on relative humidity

Intensive Properties

Single scattering albedo $\tilde{\omega}_0 = \frac{s_p}{s_p + a_p}$

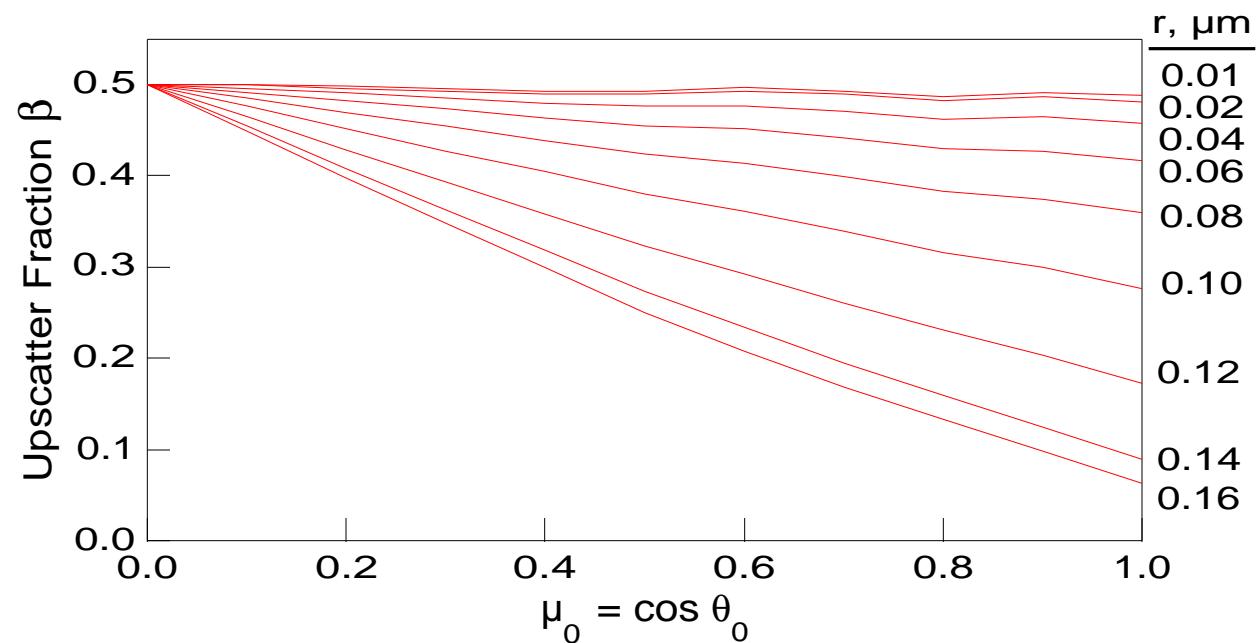
Phase function, $P(\theta)$



Backscatter fraction, b_{sp} / s_p

Ångström exponent $b, -b$

DEPENDENCE OF UPSCATTER FRACTION FOR SINGLE PARTICLE SCATTERING ON PARTICLE SIZE AND SOLAR ZENITH ANGLE



LOCAL CLOSURE EXPERIMENTS (Cubic centimeter experiments)

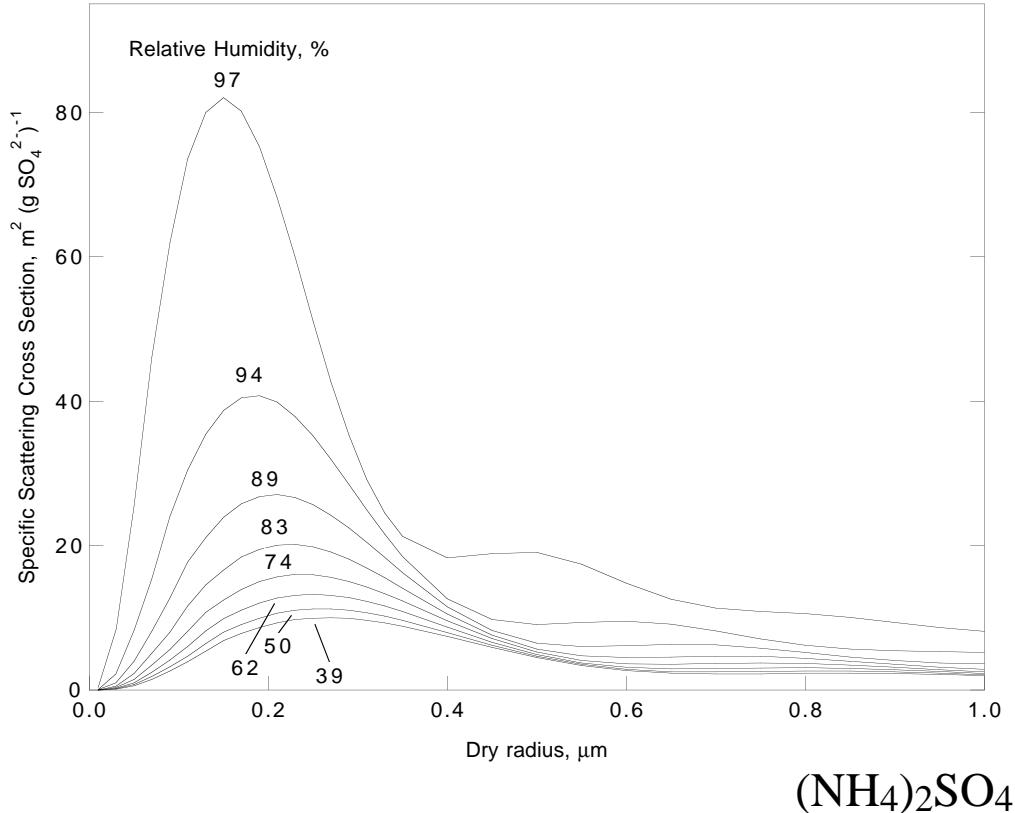
Optical property equals integral over size distribution:

$$\sigma_{\text{sp}} = \int \pi r^2 Q_s \left(\frac{r}{\lambda}, n \right) N(r) dr$$

Q_s = Mie scattering efficiency

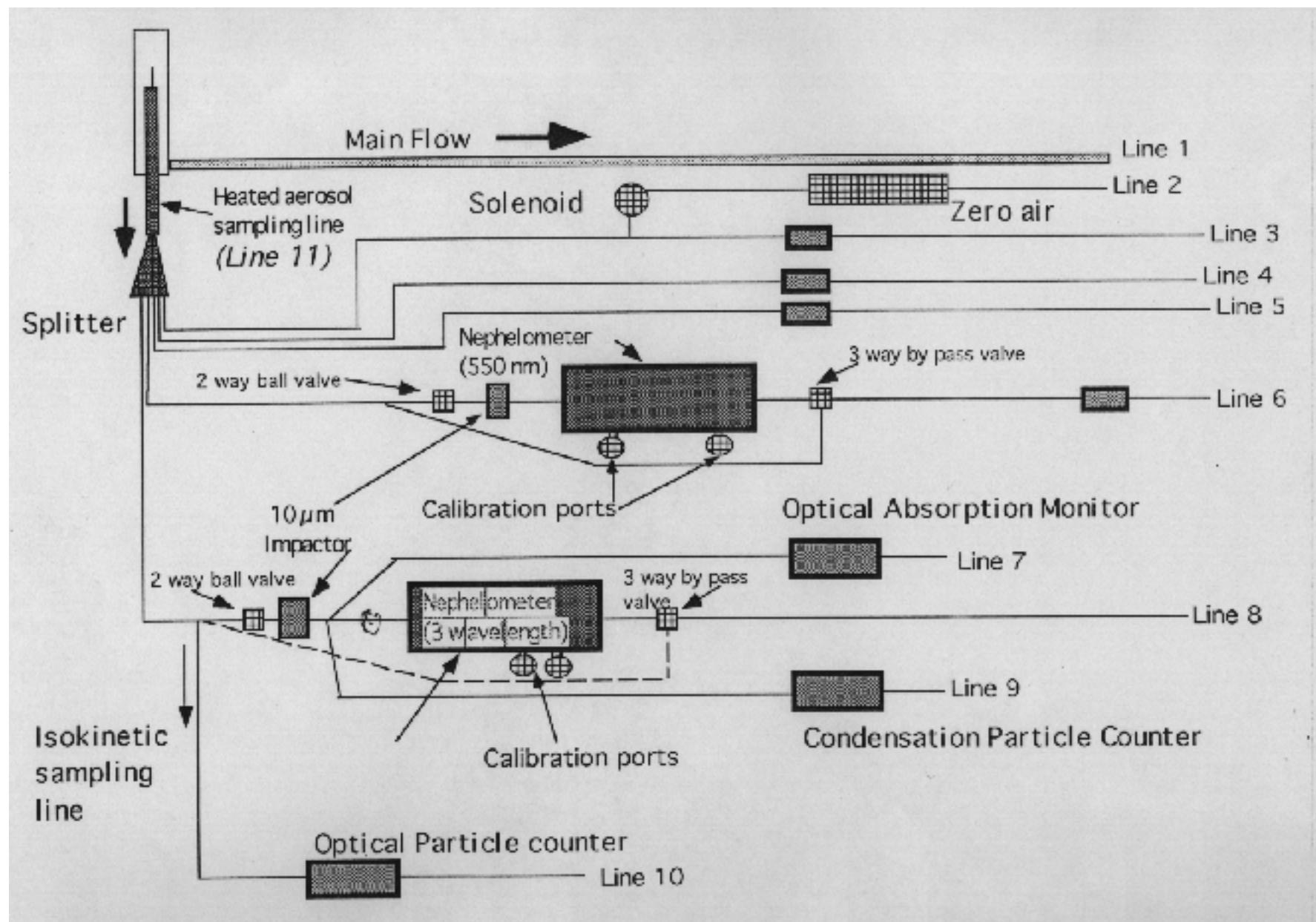
n = index of refraction

Relative Humidity Dependence of scattering:



This can be mapped out locally by determination of RH dependence of σ_{sp} and related to composition.

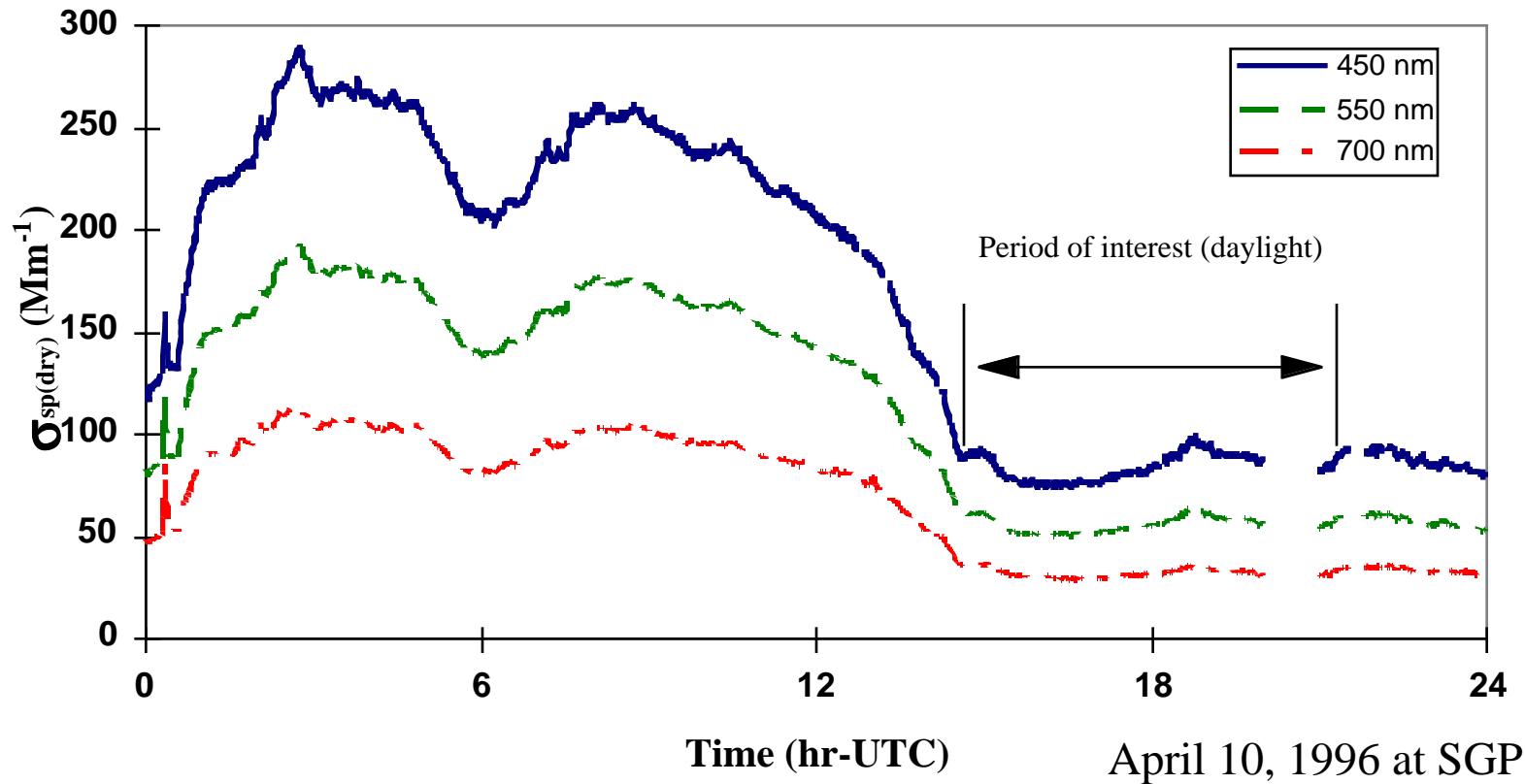
SCHEMATIC OF AEROSOL OBSERVATION SYSTEM AT SGP CENTRAL FACILITY



AEROSOL OBSERVATION SYSTEM AT SGP CENTRAL FACILITY

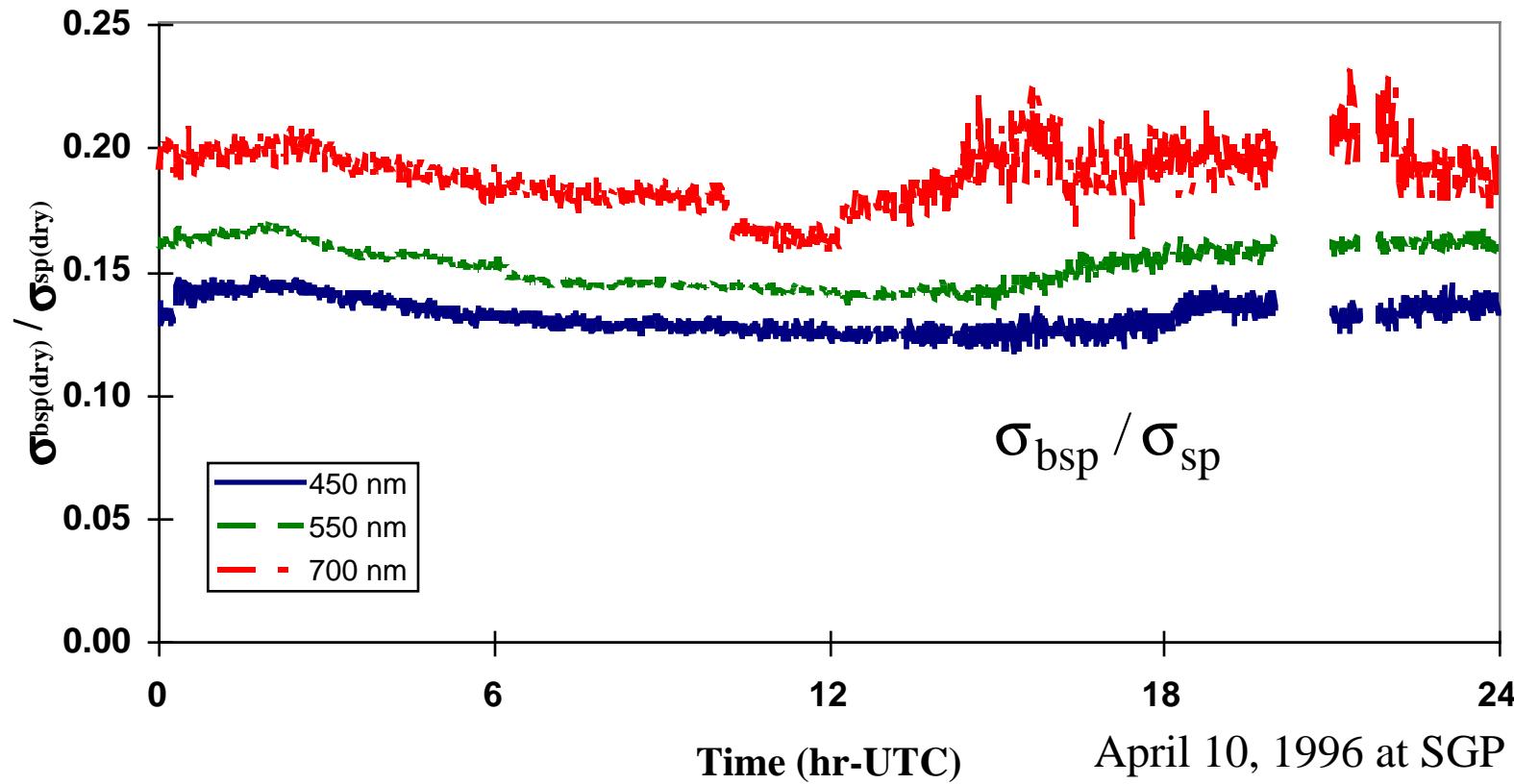


TIME DEPENDENCE OF AEROSOL LIGHT SCATTERING COEFFICIENT (DRY)



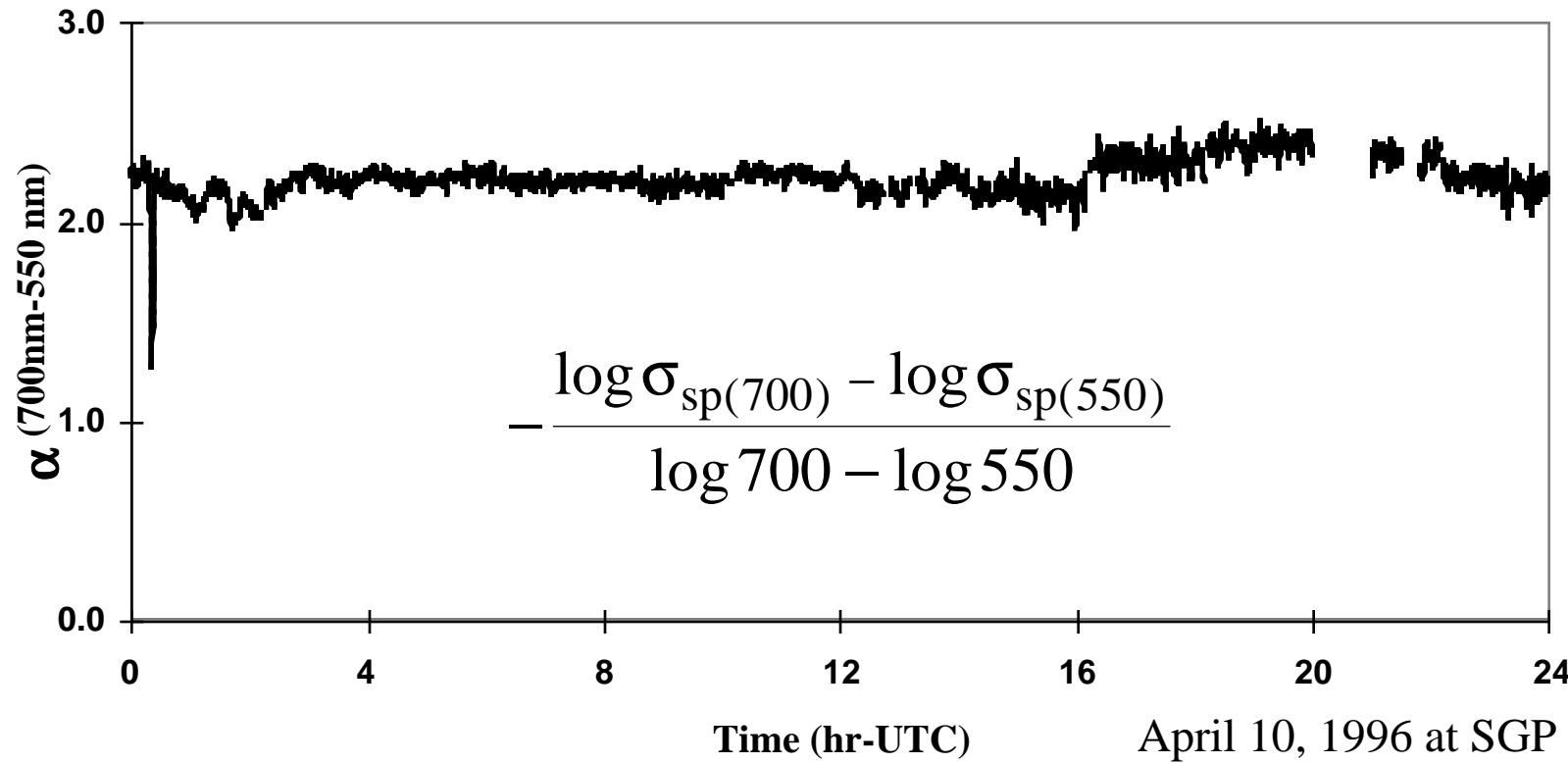
$\sigma_{\text{sp(dry)}}$, *extensive property*, varies considerably with time reflecting variable aerosol loading, (relatively constant during daylight hours).

TIME DEPENDENCE OF AEROSOL HEMISPHERIC BACKSCATTER FRACTION (DRY)



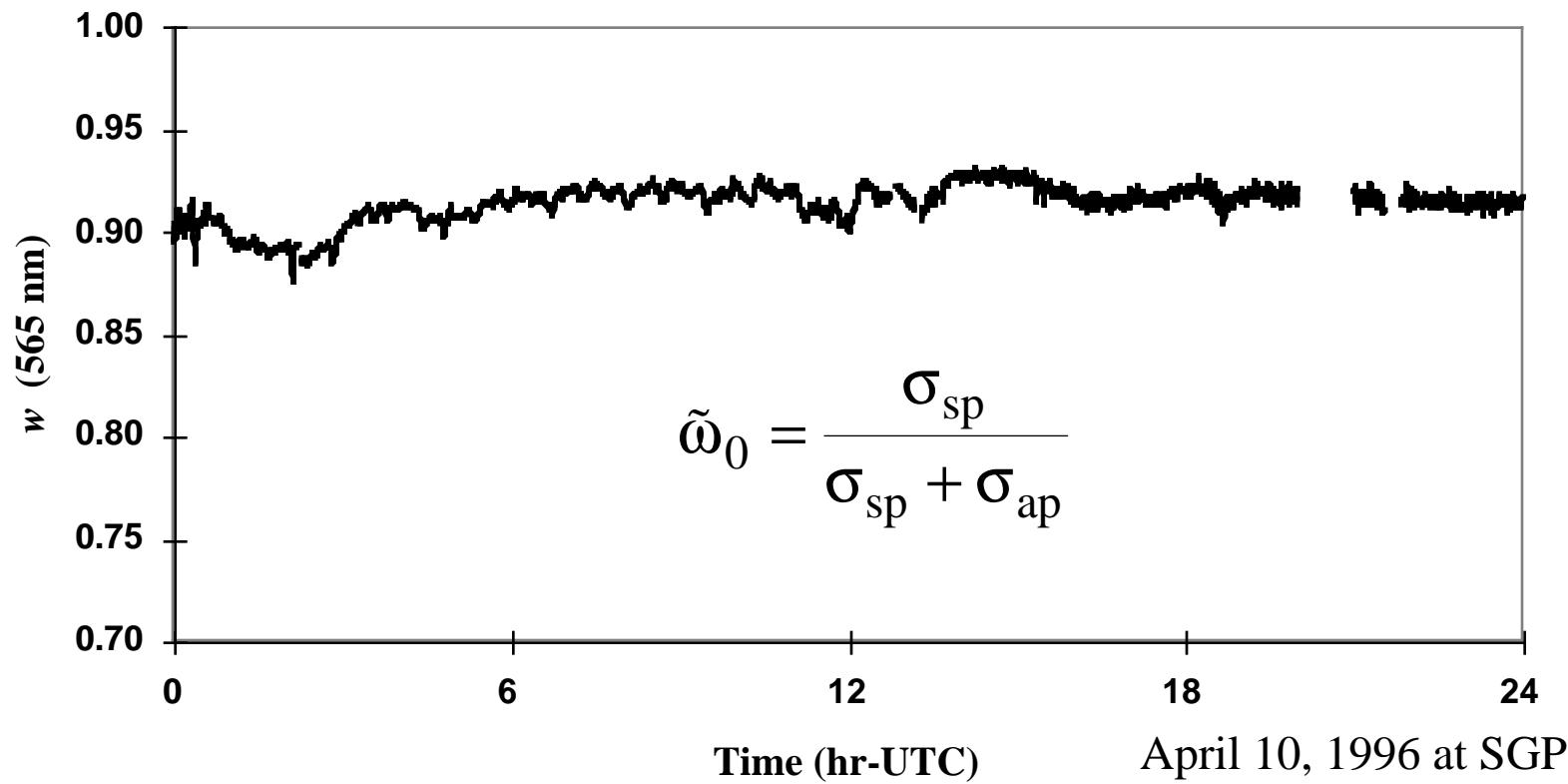
Hemispheric backscatter fraction, *intensive property*, is relatively constant with time.

TIME DEPENDENCE OF ÅNGSTRÖM EXPONENT (DRY)



Ångström exponent, *intensive property*, is relatively constant with time.

TIME DEPENDENCE OF SINGLE SCATTERING ALBEDO (DRY)



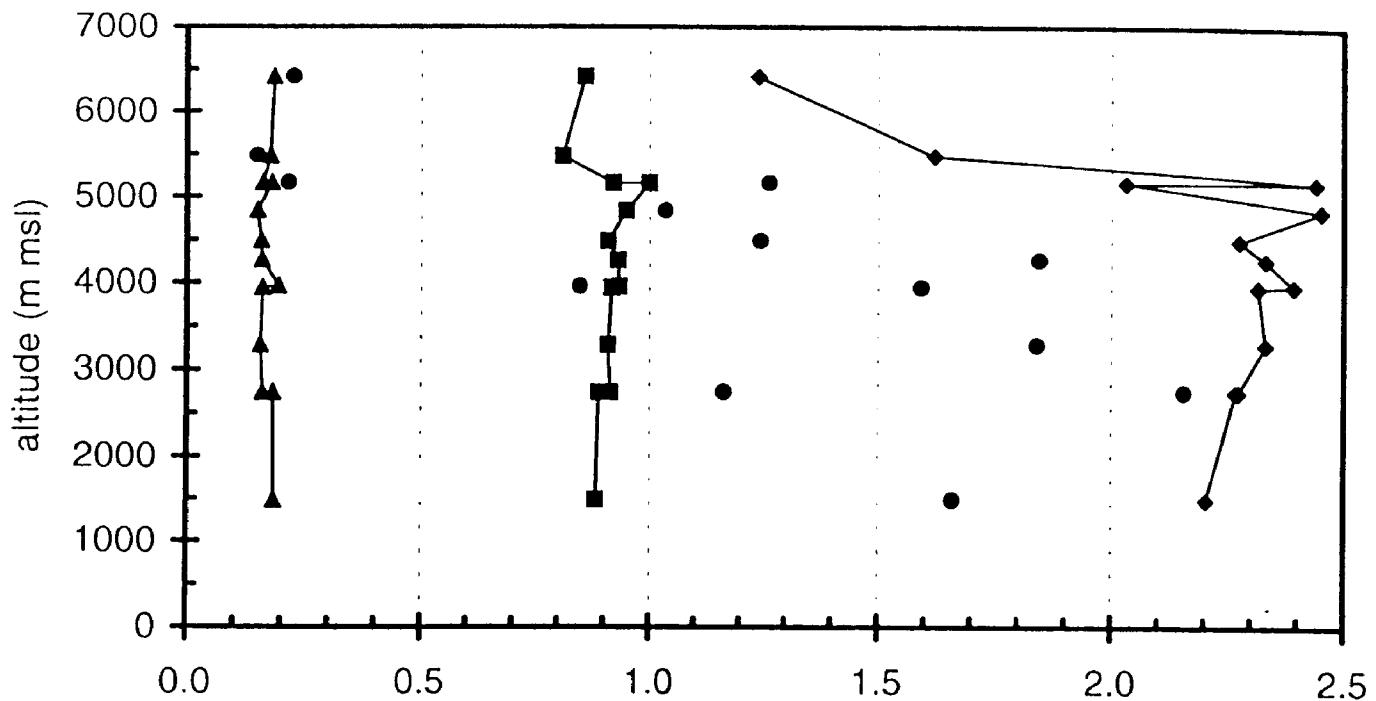
Single scattering albedo, *intensive property*, is relatively constant with time.

ARM AEROSOL HOME PAGE

http://www.archive.arm.gov/research/aerosols/dayshow/aerosol_dayshow.html

This web page is updated on a daily basis during the week day using the raw data taken during the previous 24-period.

VERTICAL PROFILE OF AEROSOL PROPERTIES



Single Scattering Albedo ■

Ångström Exponent ♦

Backscatter Fraction ▲

Scattering coefficient sp ●

Colorado, 6-14-95
Ogren and Sheridan, 1996

COLUMN CLOSURE EXPERIMENTS

Aerosol optical depth equals integral over vertical distribution:

$$\begin{aligned} a &= \int_{ep} (z, RH) dz \\ &= \int_{sp} (z, RH) / \rho_0 dz \end{aligned}$$

Requires knowledge of vertical structure of ρ_{ep} .
Lidar probing.

In-Situ measurement.

Requires knowledge of ρ_{ep} at ambient RH, vertically.

Other column closure experiments can be defined in downwelling irradiance, direct-normal solar irradiance, etc.

AEROSOL OPTICAL DEPTH

(Direct Beam Sun Photometry)

Bouguer-Lambert-Beer law:

$$\text{aerosol} = \frac{1}{m} [\ln V_0 - \ln V_{d-n}] - \text{Rayleigh} - \text{ozone}$$

m = number of airmasses in path sec(SZA)

V_{d-n} = instrument response to direct-normal radiation

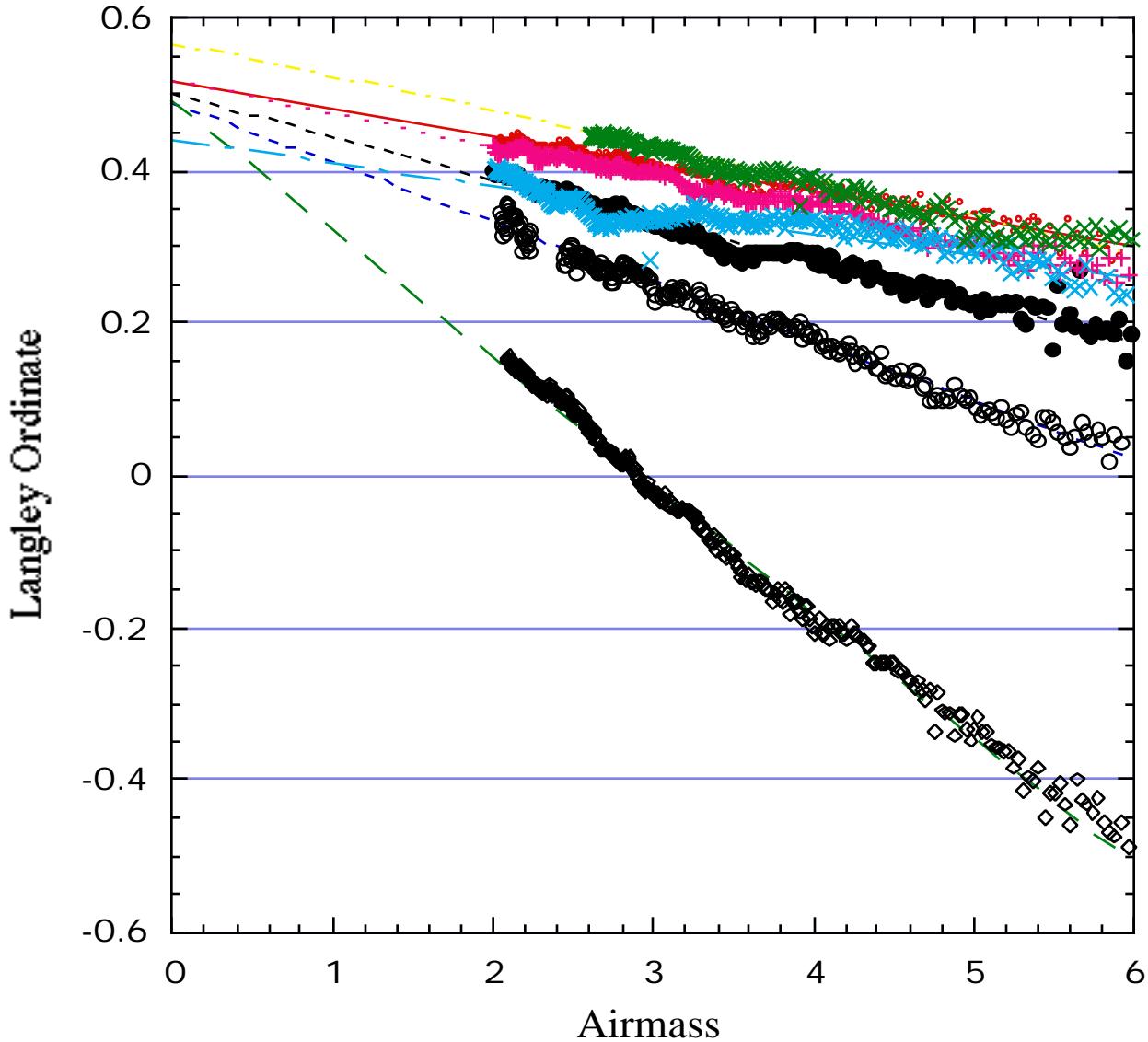
V_0 = instrument response to direct -normal radiation extrapolated to TOA.

Error in estimate of aerosol optical thickness:

Provided all other contributions to error are small, uncertainty in aerosol optical thickness is dominated by uncertainty in V_0 :

$$\text{aerosol} = \frac{1}{m} \frac{V_0}{V_0}$$

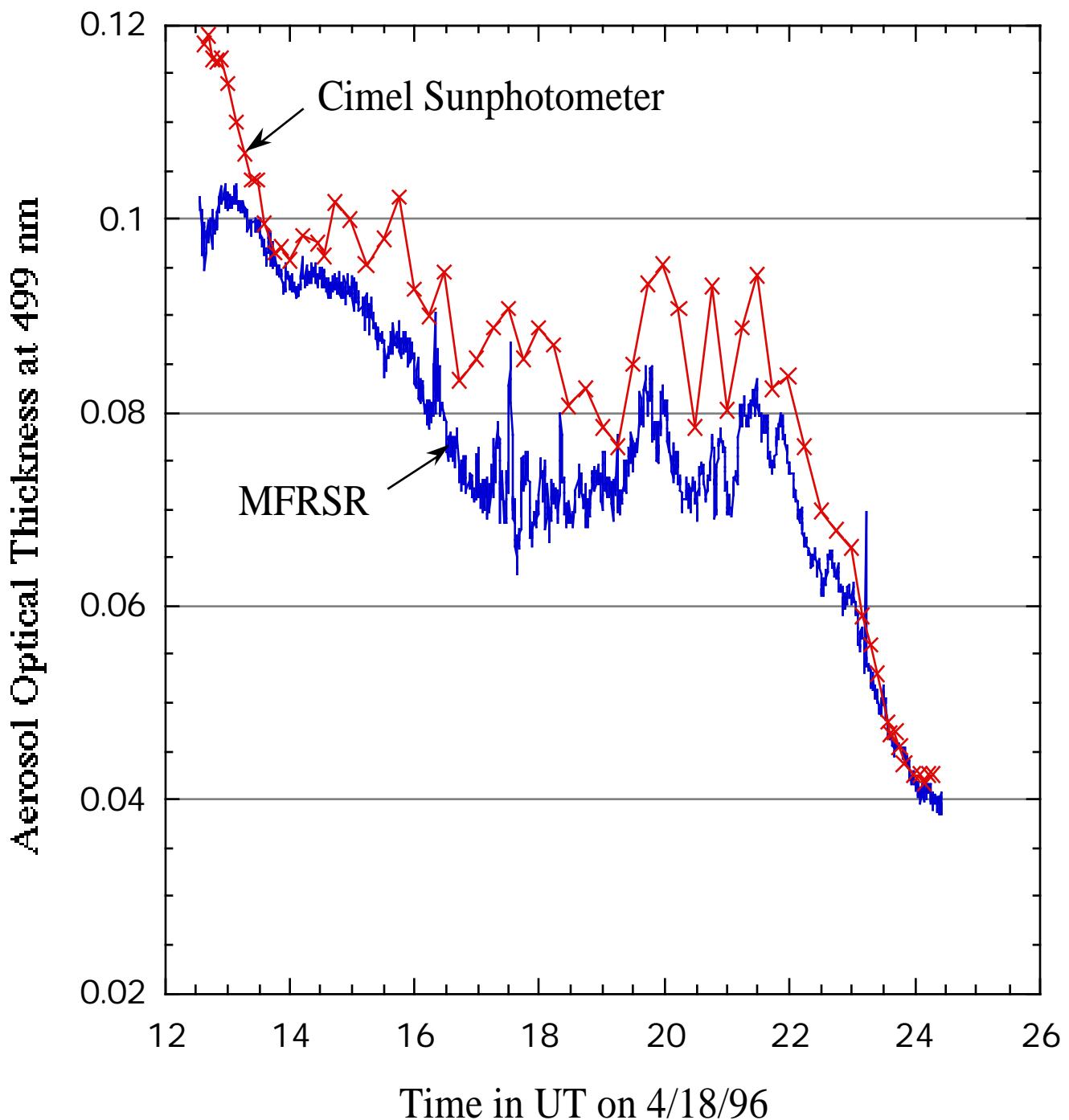
Langley Plots, 10/95 (MFRSR)



Langley intercept V_0 is derived from selected plots exhibiting maximum linearity (constant aerosol properties during morning or evening).

$$\text{aerosol} = \frac{1}{m_a} \frac{V_0}{V_0}$$

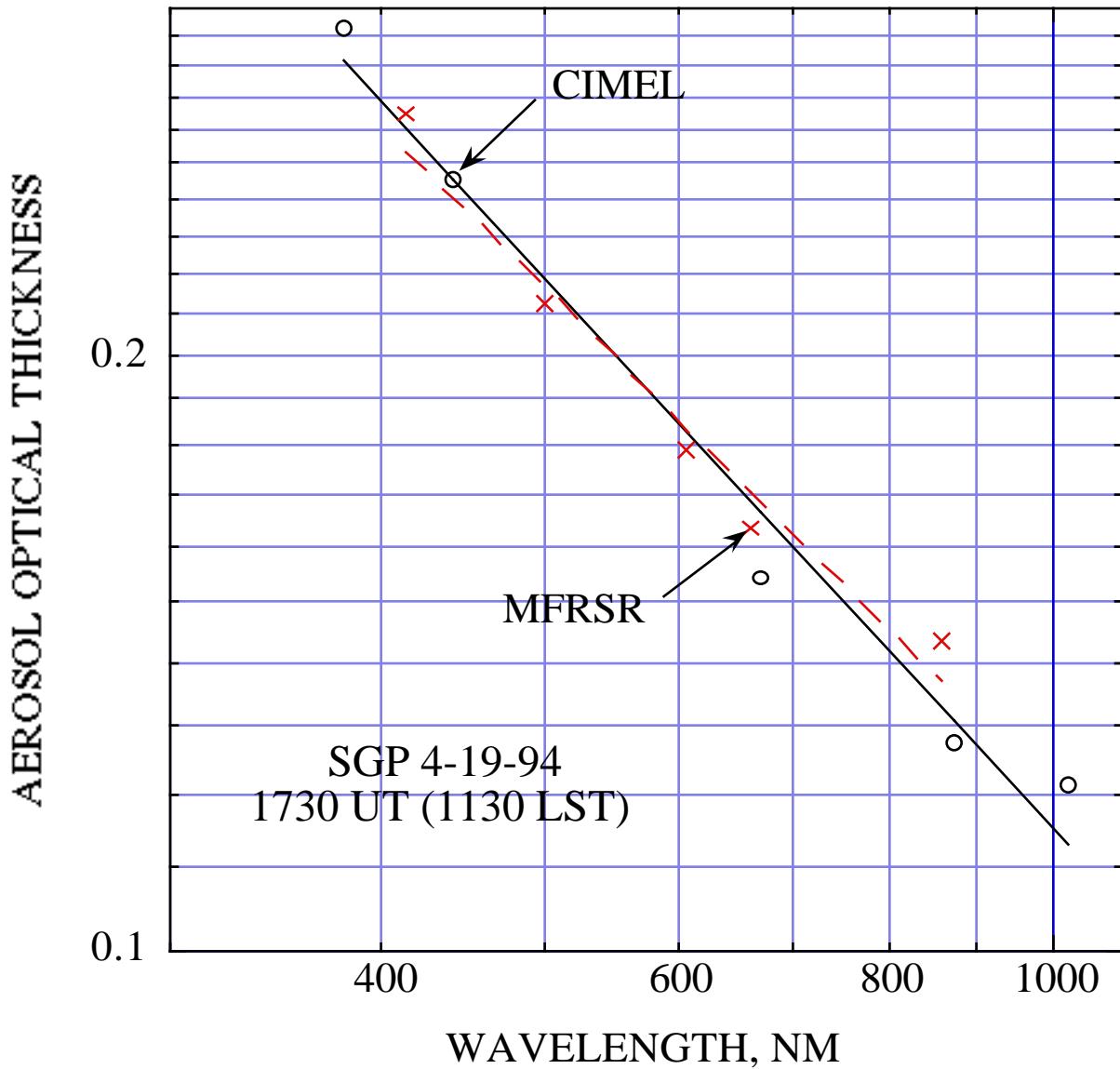
TIME DEPENDENCE OF AEROSOL OPTICAL DEPTH



CART SGP, April 18, 1996.

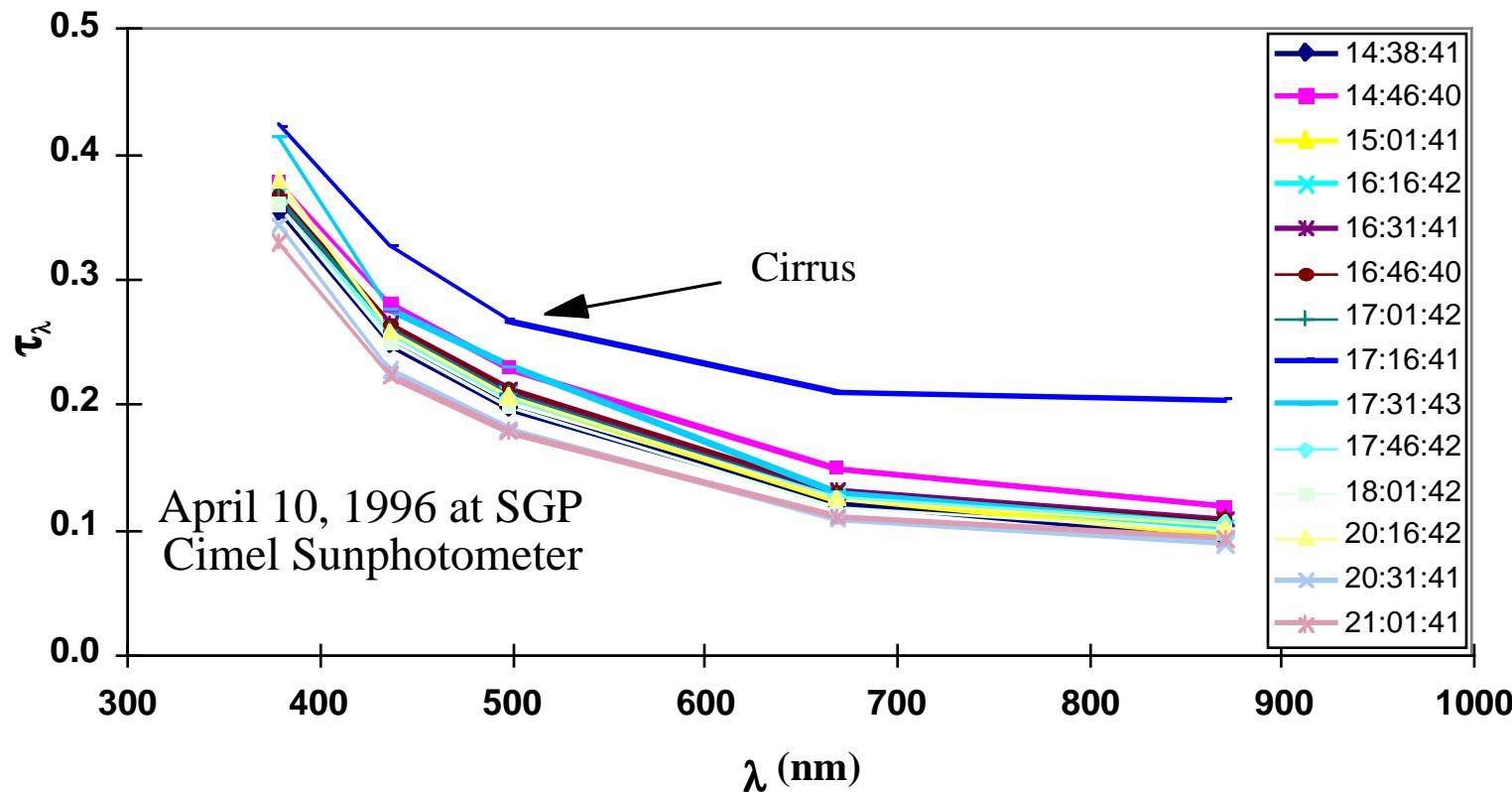
Disagreement is within accuracy of the two instruments and may be due in part to misleveling of the sensor head of the MFRSR.

ÅNGSTRÖM PLOTS SHOWING DEPENDENCE OF AEROSOL OPTICAL DEPTH ON WAVELENGTH



Note close agreement in magnitude of AOD and slope (Ångström exponent) between Cimel sunphotometer (0.840) and Multi-Filter Rotating Shadowband Radiometer (MFRSR), (0.833).

MEASUREMENTS OF AEROSOL OPTICAL DEPTH



Note decrease in wavelength dependence associated with thin cirrus ~1716 UT.

SENSITIVITY OF DIRECT-NORMAL SOLAR IRRADIANCE (DNSI) TO ATMOSPHERIC VARIABLES

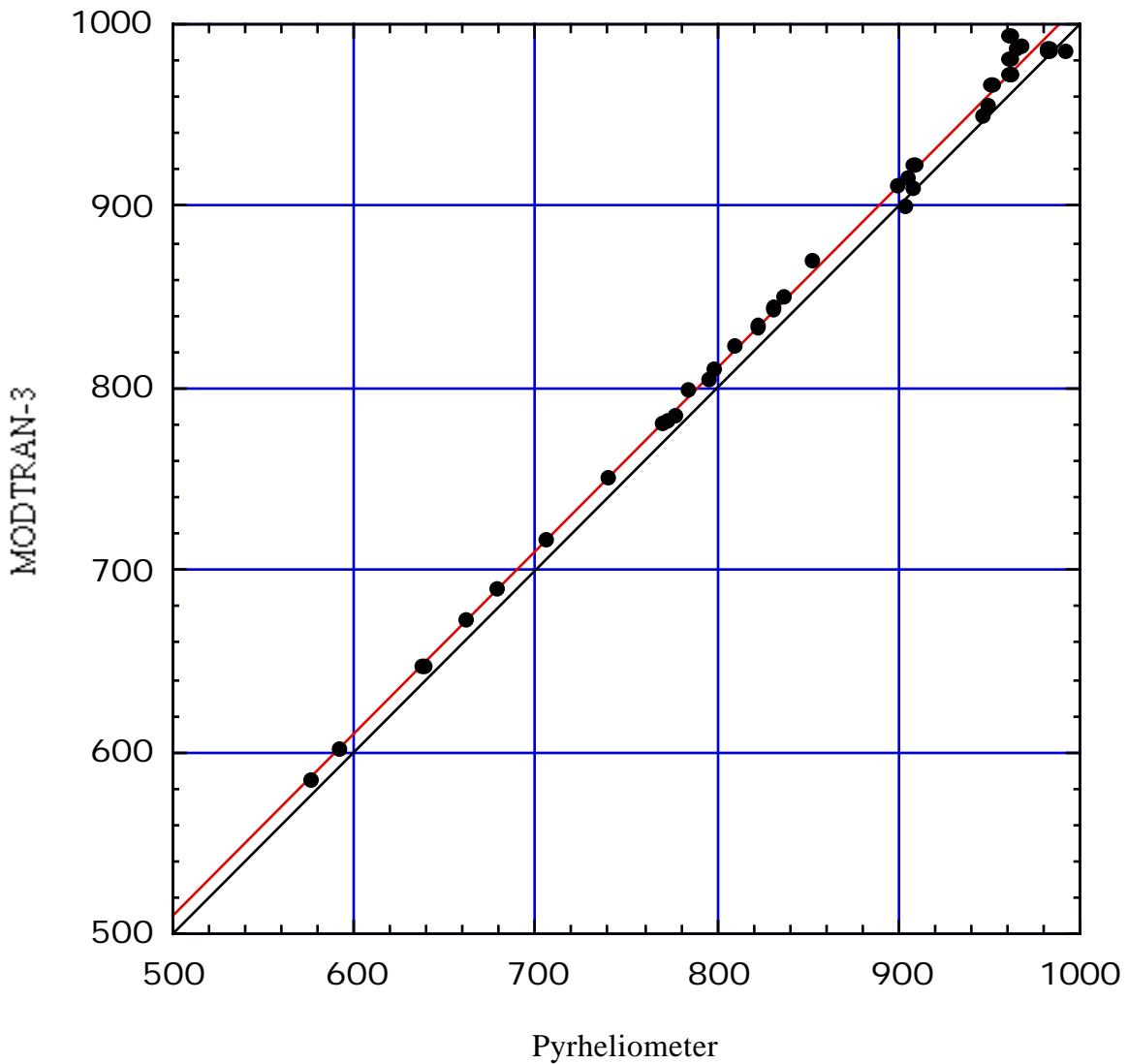
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† MODTRAN-3. Assumed Solar Constant 1373 W m⁻².

Pyrheliometer DNSI:	801.5 W m ⁻² .	Corrected for forward scattering:	798.2 W m ⁻² .
Calculated DNSI:	805.9 W m ⁻² .	Corrected for irradiance beyond 5 μm :	809.9 W m ⁻² .
Absolute Difference 11.7 W m ⁻² .		Fractional Difference: 1.4%.	

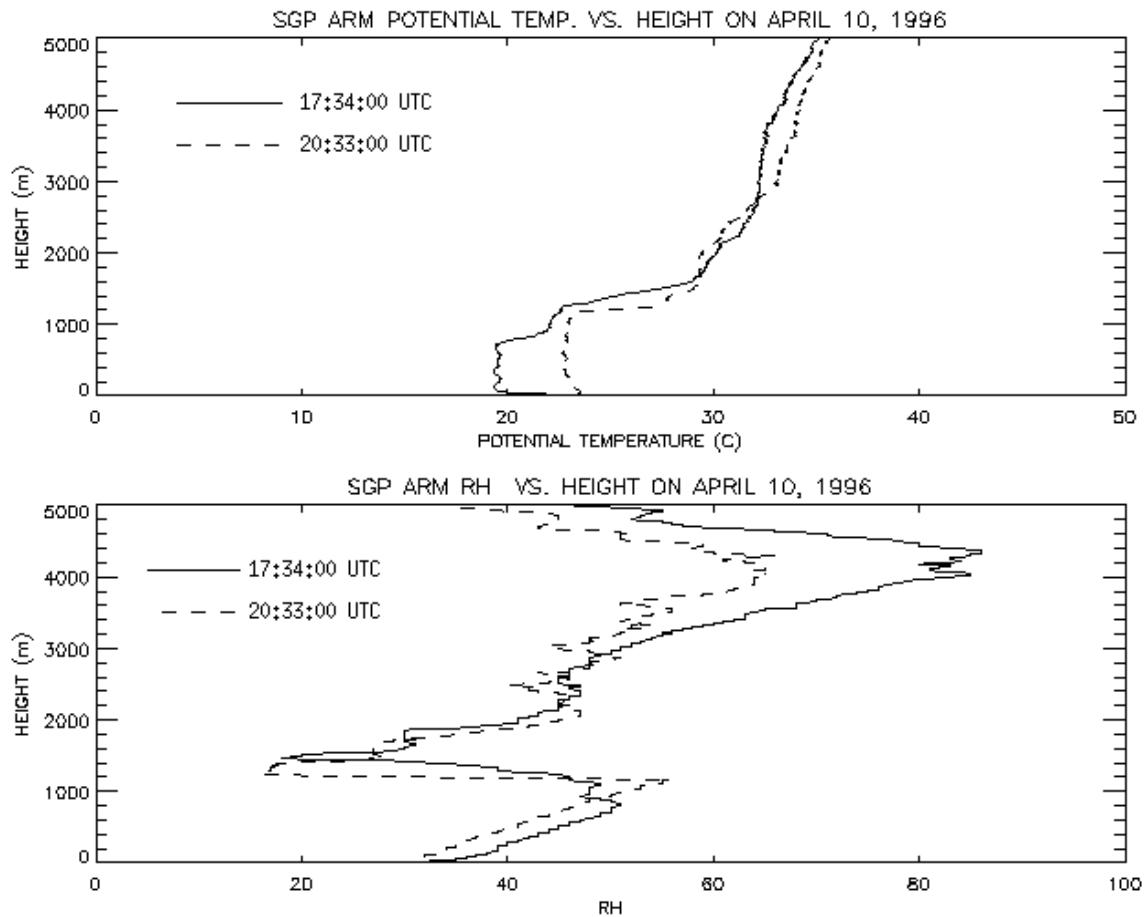
SUMMARY OF DNSI COMPARISONS



- Measurements by an Absolute Cavity Radiometer (calibrated against World Radiation Reference Standards at Davos, Switzerland, October, 1995) and Normal-Incidence Pyrheliometer.
- The correlation is excellent but with ~1.5% bias.

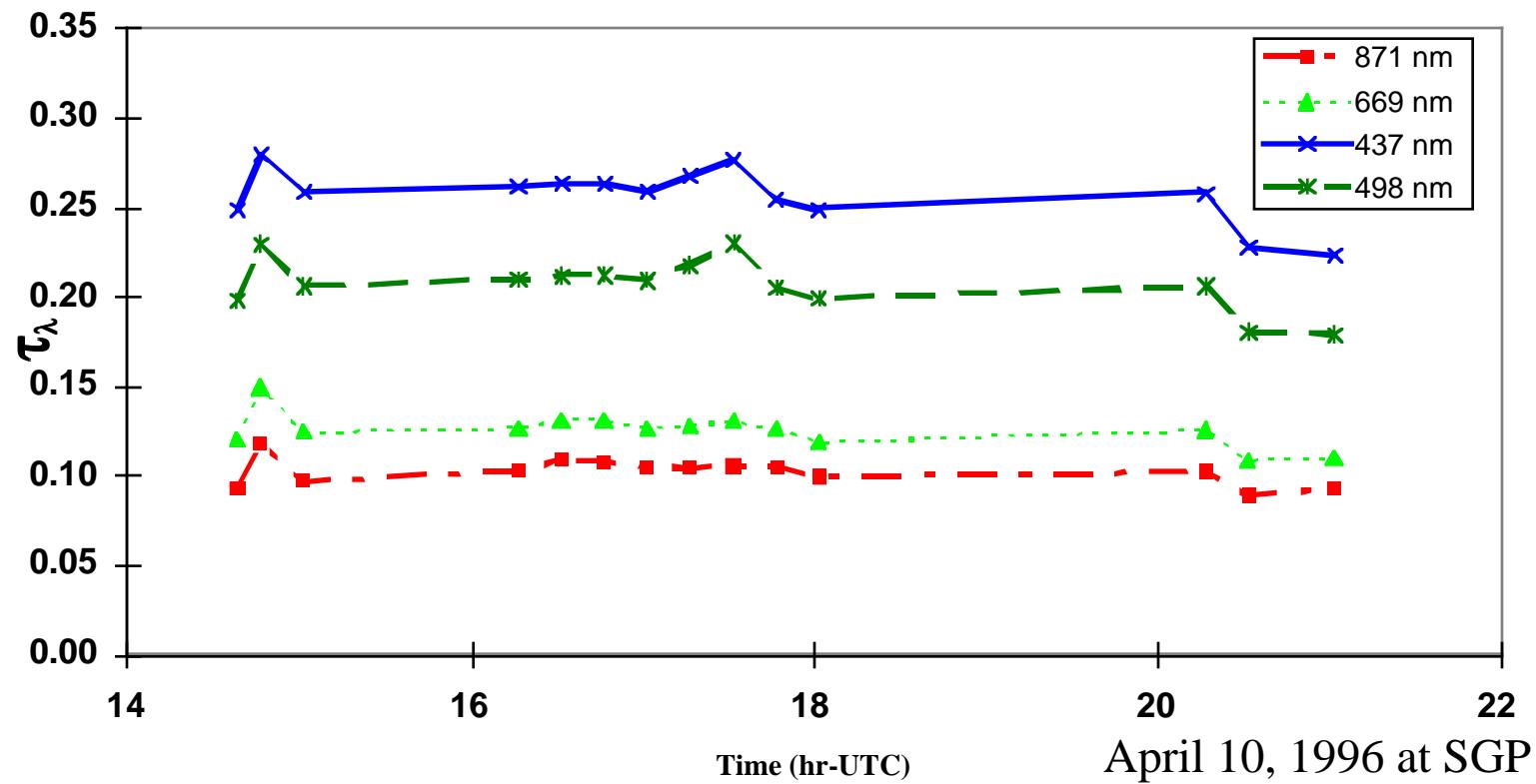
ATTEMPTED CLOSURE EXPERIMENT IN AEROSOL OPTICAL DEPTH BASED ON SURFACE AEROSOL PROPERTIES

$$\begin{aligned}
 a &= \int_{\text{sp}}^{\text{ep}} (z, \text{RH}) dz \\
 &= \int_{\text{sp}(0, \text{RH}_{\text{dry}})}^{\text{ep}} (z, \text{RH}) / f(\text{RH}) dz \\
 &\quad z_{\text{mixed layer}}
 \end{aligned}$$



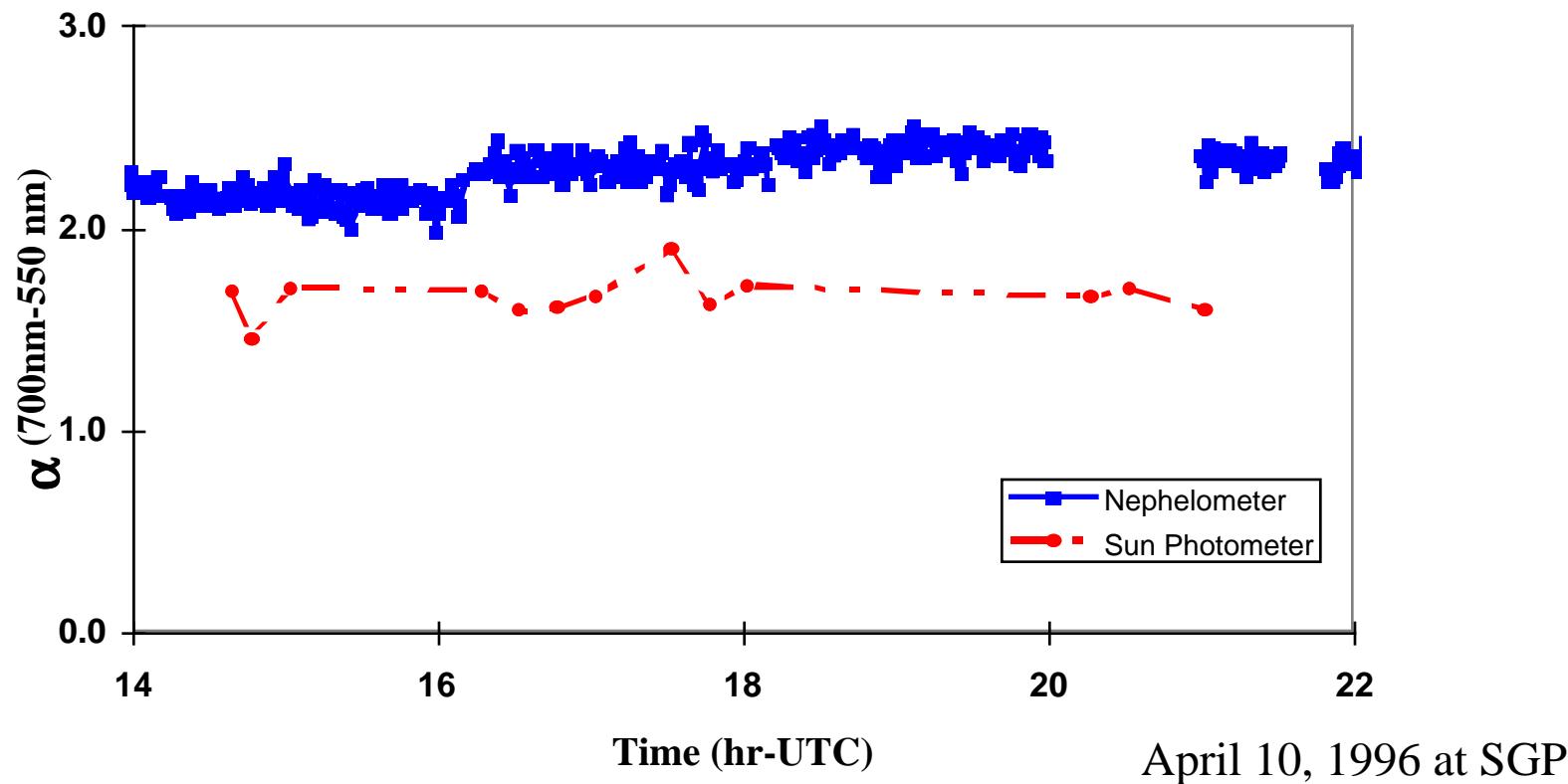
The mixed layer height, $z_{\text{mixed layer}}$, is roughly 1200 m.

TIME DEPENDENCE OF AEROSOL OPTICAL DEPTH



Aerosol optical depth, *an extensive property*, happens to be rather constant with time during the period 1500 to 2000 UT.

ÅNGSTRÖM EXPONENT NEPHELOMETER VS. SUNPHOTOMETER



Ångström exponent is greater in light scattering coefficient than in optical depth showing decrease in particle size in nephelometer relative to atmospheric column.

COMPARISON OF MEASURED AND CALCULATED AEROSOL OPTICAL DEPTH

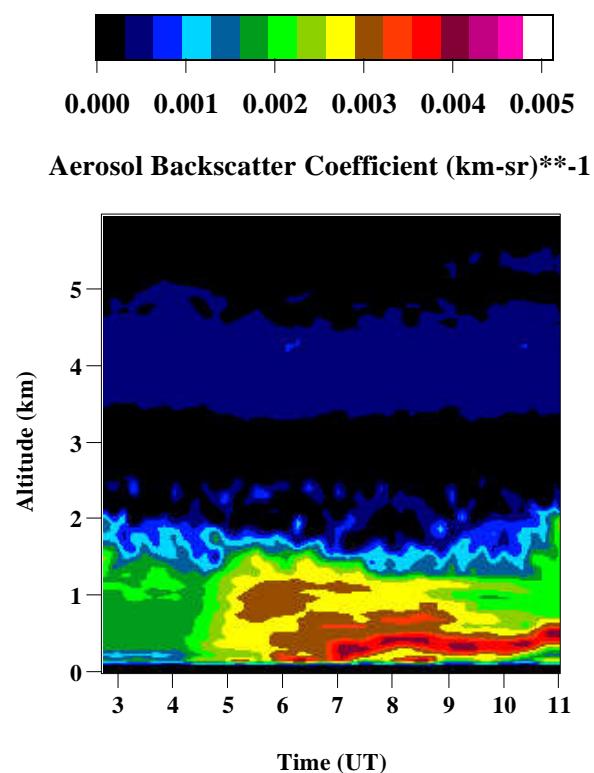
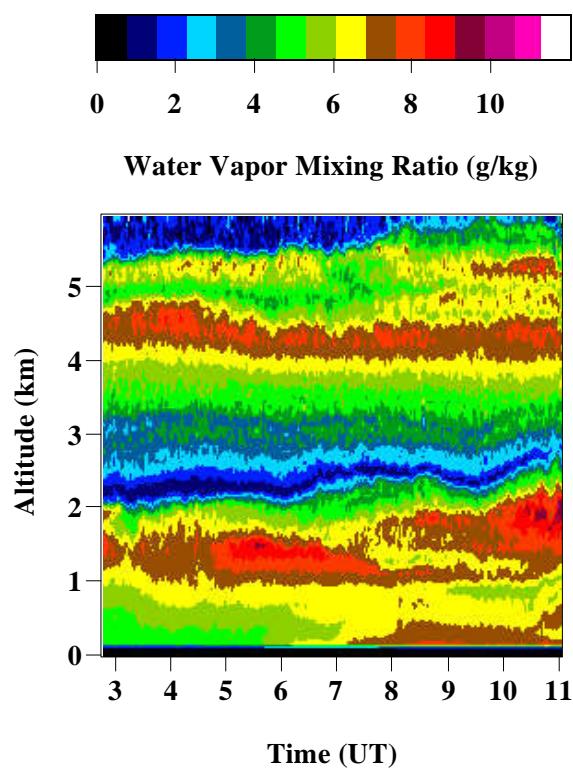
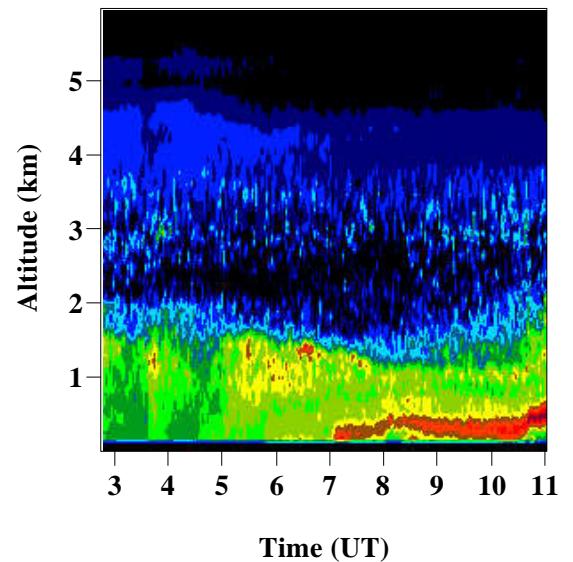
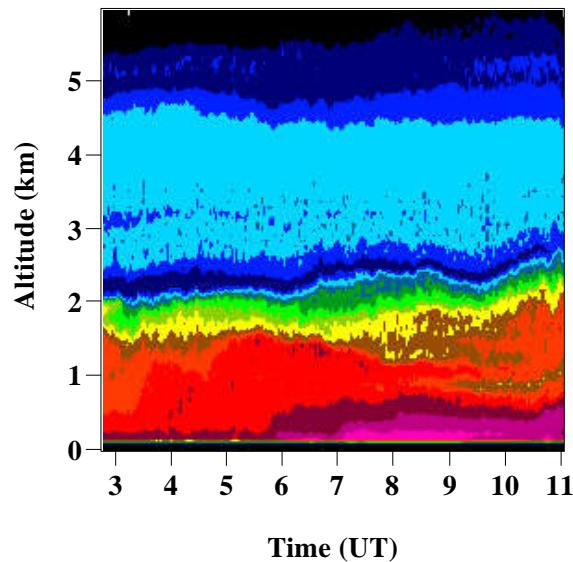
, nm	neph ($f = 1$)	neph ($f = 1.5$)	sunphotometer	Difference	Ratio
450	0.11	0.15	0.24	0.09	1.6
550	0.07	0.11	0.18	0.07	1.6
700	0.04	0.06	0.12	0.06	2.0

1400 to 2100 UT, April 10, 1996, SGP

$z_{\text{mixed layer}}$, taken as 1200 m.

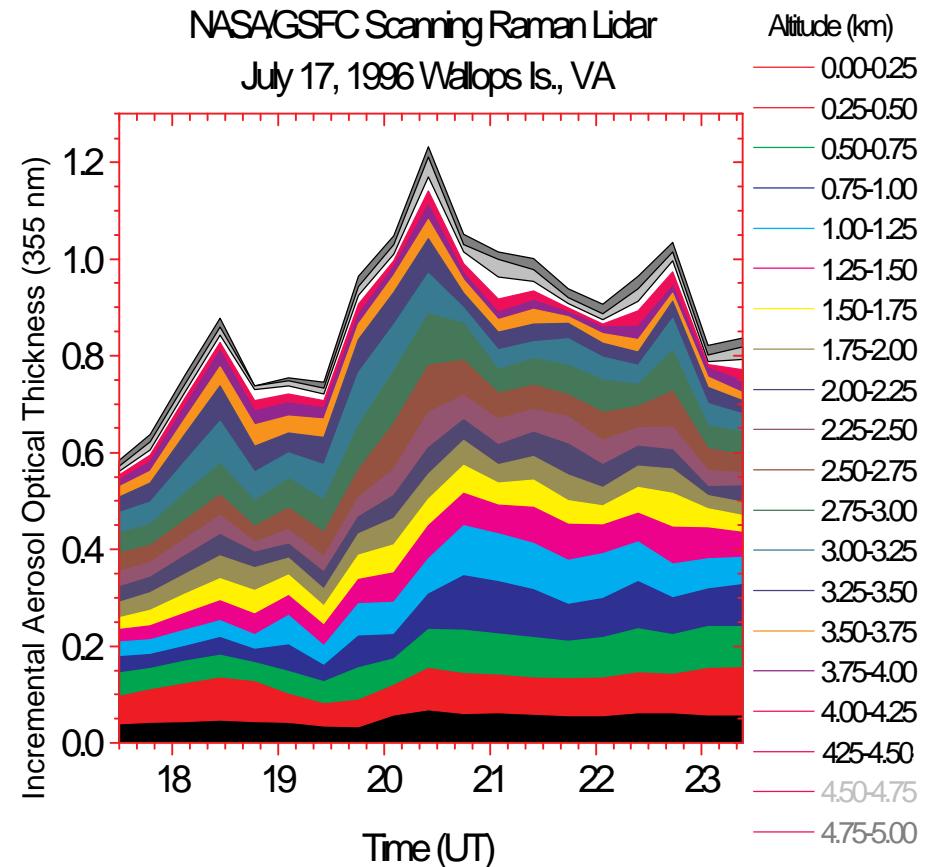
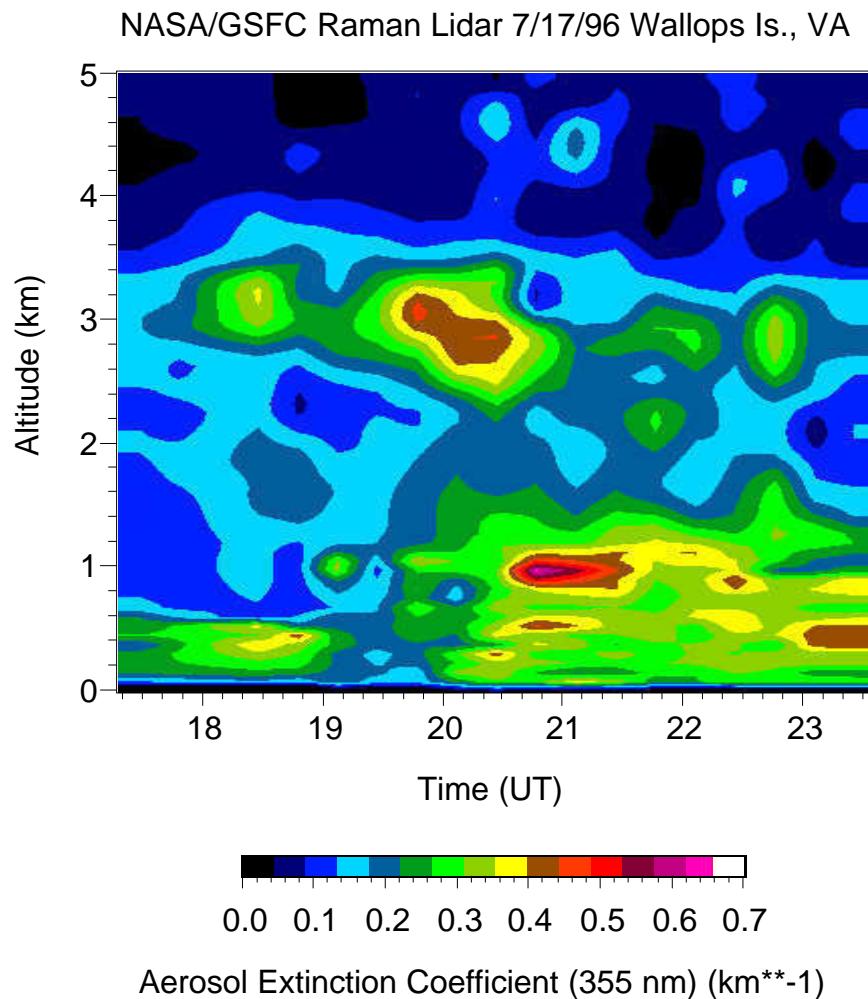
- The discrepancy suggests additional contribution to AOD from aerosol above the mixed layer, or inappropriate correction for relative humidity dependence of scattering coefficient.
- Such discrepancies require better characterization of the vertical distribution of aerosol properties.

NASA GSFC RAMAN LIDAR FOR WATER VAPOR AND AEROSOL



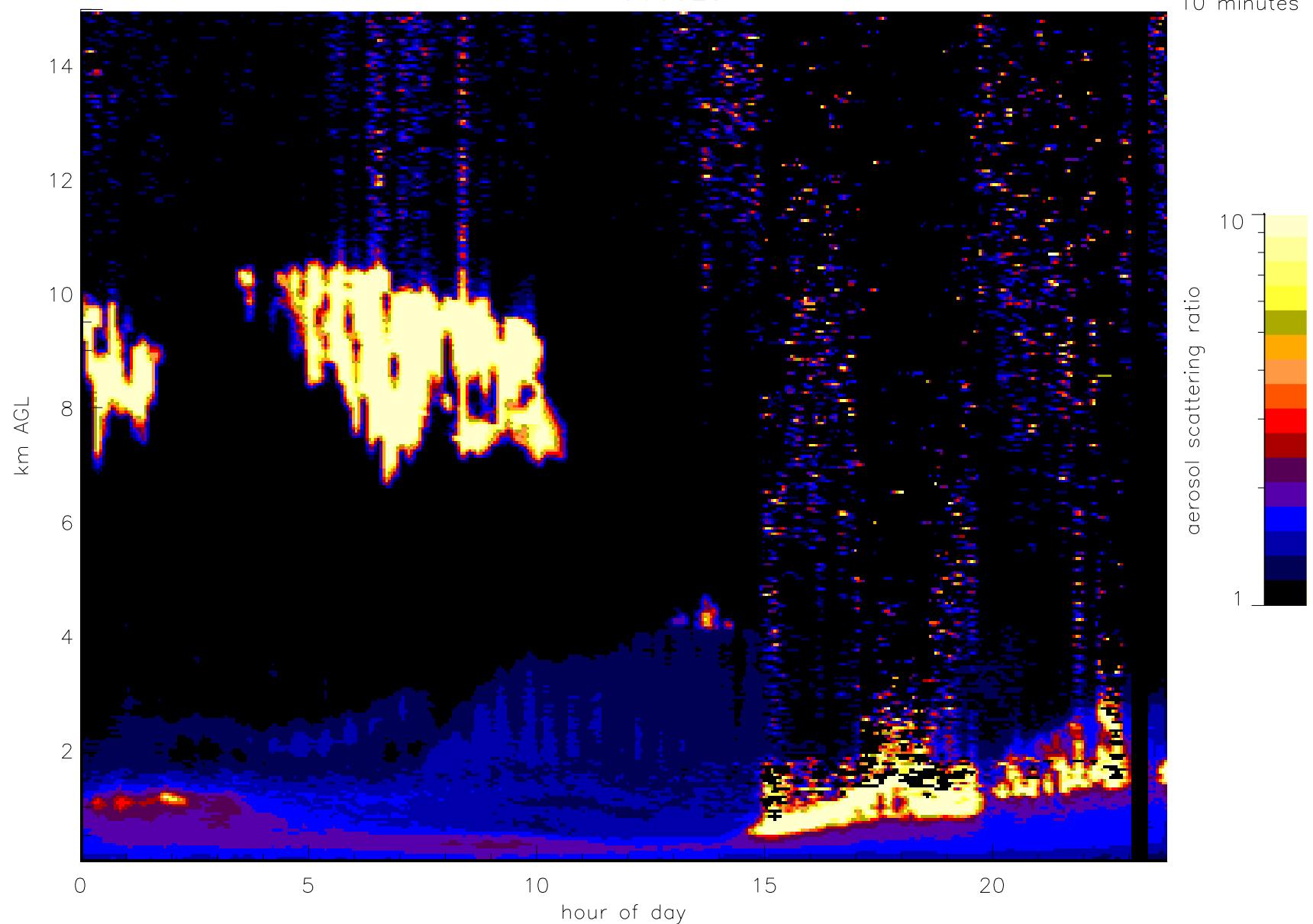
SGP, April 21, 1994

NASA GSFC SCANNING RAMAN LIDAR



Merged raman lidar aerosol data
960923

Averaging interval
10 minutes



CONCLUSIONS

- Aerosol optical depth must be accurately accounted for in column radiative closure studies. At SZA of 60° an uncertainty of 0.01 in AOD corresponds to an uncertainty of 13 W m^{-2} (1.7%) in instantaneous DNSI.
- When aerosol optical depth is accurately determined, DNSI can be closed to $\sim 12 \text{ W m}^{-2}$ (1.5%).
- The closure of DNSI to with MODTRAN-3 suggests no major direct beam extinction not accounted for by that model, and by extension, no major unrecognized atmospheric absorption.
- The high sensitivity of aerosol scattering to RH requires careful attention in column closure experiments on aerosol optical depth, even with *in-situ* aircraft characterization of aerosol properties.